84_5

GR-84-5

PHOTOVOLTAIC REMOTE CATHODIC CONTROL AND MONITORING BY SATELLITE

NEWARK PUBLIC LIBRARY
OCT 1 0 1985
U. S. GOVT. PUBS.
DEPOSITORY 378

July 1985
Engineering and Research Center

U.S. Department of the Interior
Bureau of Reclamation
Division of Research
and Laboratory Services
Power and Instrumentation Branch

T55.29
READER

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
GR-84-5		

4. TITLE AND SUBTITLE	5. REPORT DATE
Photovoltaic Remote Cathodic Control And Monitoring By Satellite	July 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
M. Gutierrez, M. Freed, S. Stitt	GR-84-5
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Bureau of Reclamation Engineering and Research Center Denver, Colorado 80225	11. CONTRACT OR GRANT NO.
	13. TYPE OF REPORT AND PERIOD COVERED
12. SPONSORING AGENCY NAME AND ADDRESS	
Same	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the E&R Center, Denver, CO

Editor: J.T.C.

16. ABSTRACT

A study was undertaken to determine how solar energy could be used for cathodic control in remote areas and for monitoring cathodic signals remotely by satellite. This report pertains to the electronic instrumentation, interfacing, and signal conditioning of cathodic signals for remote monitoring by satellite at the Marston Water Treatment Plant. At the Marston site a field of 120 pieces of 10-foot-long pipe made from various materials is being studied. Once every hour cathodic data are transmitted by satellite to the Bureau's E&R Center for analysis. Information is stored and retrieved for analysis at a later time by the investigator.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- / *data collection systems/ remote sensing/ cathodic protection/ *corrosion control

b. IDENTIFIERS-- Marston Water Treatment Plant

c. COSATI Field/Group 13 COWRR: 1308 1113 SRIM:

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 30
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE

GR-84-5

PHOTOVOLTAIC REMOTE CATHODIC CONTROL AND MONITORING BY SATELLITE

by

M. Gutierrez
M. Freed
and
S. Stitt

Power and Instrumentation Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

July 1985

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

This investigation and work were conducted for the Department of Energy by the Bureau of Reclamation, Division of Research – by personnel from the Applied Sciences Branch – Materials Science Section and by personnel from the Power and Instrumentation Branch, Automation Section.

Special thanks go to Michael Freed of the Automation Section for his work in the construction and wiring of the PC boards; to Harry K. Uyeda from the Materials Science Section for help and guidance in cathodic measurement work; and to Gregory Myers from the Materials Science Section for his help with the installation of equipment at the Marston WTP site. Special acknowledgement is given to the Denver Water Board, Marston Water Treatment Plant, for the use of their land and their help trenching for the pipes.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Funding was supplied by the Department of Energy under 4520 and 4521 of the Federal Photovoltaic Utilization Program for studies of photovoltaic solar energy applications to cathodic protection control and for remote signal monitoring and display.

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm by the Bureau of Reclamation.

CONTENTS

	Page
Introduction	1
Summary and Conclusions	3
Summary	3
Conclusions	3
Purpose	3
Method	4
The Marston Water Treatment Plant Test Site	4
Pipe layout	4
Wiring connections	4
System and instrumentation	6
Photovoltaic solar panels and batteries	6
Basic principles of solar cells	9
Solapac regulator and control	9
Solapac maintenance	10
Mesonet station (probe)	10
Data transmission and collection	10
Time synchronization	12
Multiple sensor channel assignment	12
Scan circuit	15
Scan circuit theory of operation – automatic operation	15
Manual operation	15
Cathodic protection power system current and voltage interface	15
Current measurements	15
Series resistor	17
Voltage (multiplex) board – basic principles	21
Voltage board – theory of operation	21
Current multiplexer and amplifier board	21
Theory of operation	23
Timing	23
Voltage regulator and power supply	23
Data collection, transmission, and retrieval	23
Calibration	24
Maintenance	25
Electronic circuit boards	25
Battery maintenance	27
Solar Panel maintenance	27
Maintenance of other equipment	29
Test Results	29
Bibliography	30

TABLES

Table

1	Timing and channel selection	14
2	Pin connection	20
3	Data collection format for the Marston WTP site	29

CONTENTS – Continued

FIGURES

Figure		Page
1	Overall system diagram of remote data transmission and cathodic protection	2
2	Marston Water Treatment Plant site – pipe layout	5
3	Cathodic control block diagram	7
4	Power hook-up block diagram	8
5	Solapac cathodic protection regulator and circuit	11
6	Data collection system and cathodic signal interface block diagram	13
7	Display and regulator board display circuit	16
7a	Display and regulator board	17
8	Cathodic protection wiring diagram	18
9	Cathodic protection power system current and voltage interfacing	19
10	Voltage circuit board	22
10a	Voltage circuit board component layout	24
11	Current multiplexer and amplifier board	26
11a	Current multiplexer and amplifier board component layout	27
12	Energy solar cathodic protection circuits	28

INTRODUCTION

The purpose of this report is to document the electronic instrumentation, interfacing, and conditioning used to remotely monitor cathodic signals at the Marston WTP (Water Treatment Plant, Denver, Colo.) The Marston WTP was used as part of a study to determine how solar energy could be used for cathodic control in remote areas. To explain the electronic design, this report describes the other components of the system (e.g., the pipe layout, solar panels, batteries, and the satellite transmission system).

The use of PV (photovoltaics) as a power source for cathodic protection in remote areas is effective and economical. As electric power rates rise and the cost of bringing electricity to remote areas increases, the use of photovoltaics becomes increasingly attractive.

The effectiveness of using PV solar energy to cathodically protect buried structures is being realized more each day. As the costs of PV are reduced, the use of solar energy in remote areas will increase. One advantage of using PV to cathodic signal conditioning is the elimination of rectifiers.

Controlling and transmitting signals to a satellite from remote sites by solar-driven systems is a step forward in the use of solar energy. The applications of this approach are many.

The electronic design of the cathodic measuring system is straightforward but new to cathodic signal control and monitoring. A total of 64 independent signals can be monitored locally, displayed, and, in redundancy, transmitted via satellite. Multiplexing and signal conditioning are complex because of the intricate nature of cathodic signal patterns and interfacing, and the requirement for low power consumption.

The simulation of cathodic signal patterns is difficult; thus, most of the methods of signal control, monitoring, and interfacing for transmission to satellite have been done on actual structures onsite. The main objective has been to provide a functional system for remote monitoring of various phenomena pertaining to cathodic signals. The concept of remote signal monitoring using satellites is not limited necessarily to cathodic phenomena, but can be used in other areas, such as monitoring dams, canals, forests, and other facilities that require observation.

Each of the sensors is interrogated four times during a one-hour period. The information is stored in memory and transmitted five minutes after completion of the assigned hour. A pictorial drawing of the system is shown on figure 1.

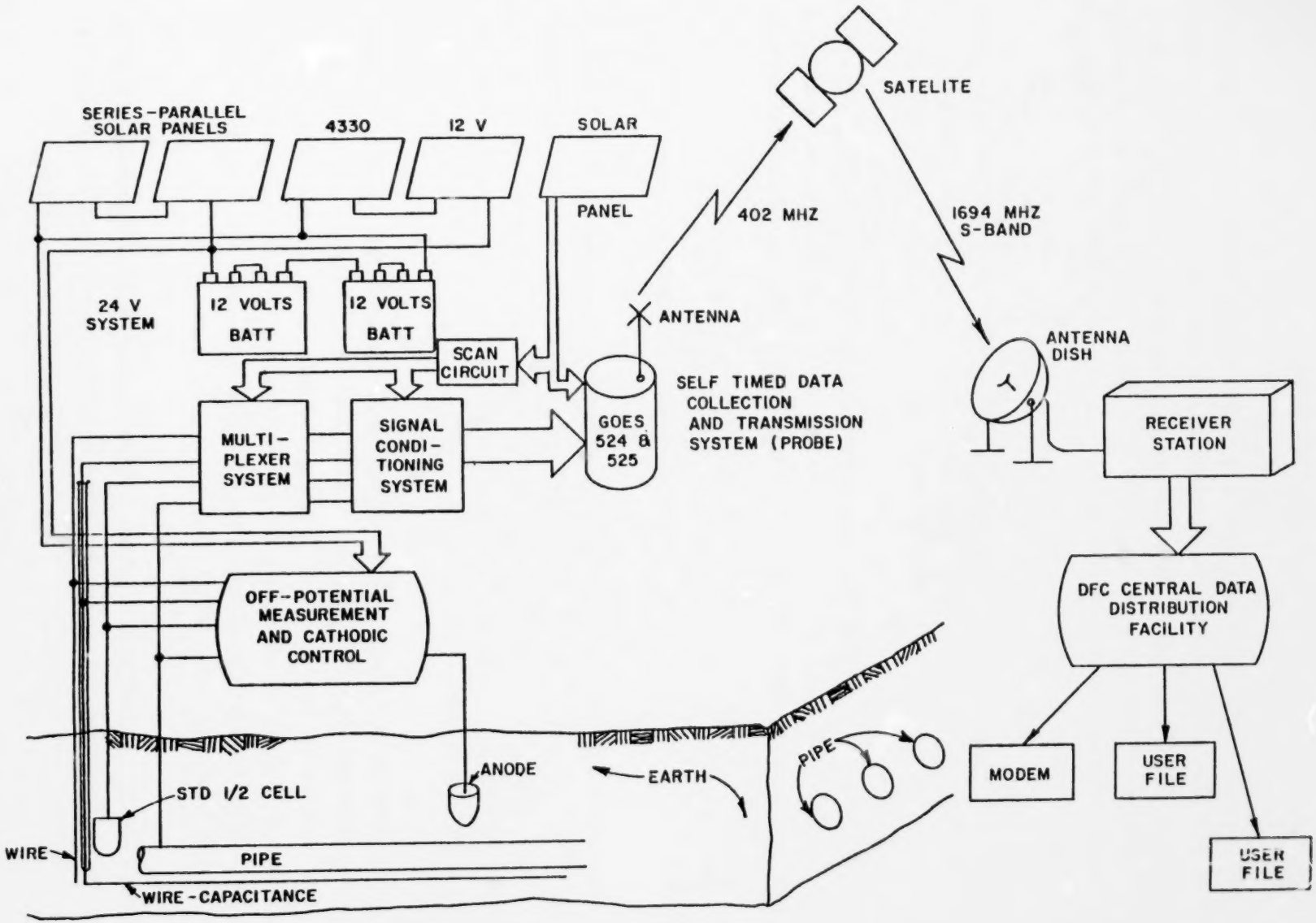


Figure 1. – Overall system diagram of remote data transmission and cathodic protection.

A series of multiplexers connected to the various pipes is multiplexed throughout the day to measure pipe-to-soil potential and pipe currents. The signal processing and multiplexing system consists of eight assigned transmitted channels, which are interrogated four times and transmitted to satellite once each hour. At the end of each hour the multiplexer is advanced one step. There are eight steps to a cycle and three cycles to a 24-hour day. Thus, each sensor's average is sampled three times a day and four times during that selected hour.

The cathodic protection, electronics, and the transmitting system are sustained by solar energy. A series of photovoltaic cells provides the necessary power continuously to control and monitor the cathodic potential necessary to keep the pipes from corroding.

SUMMARY AND CONCLUSIONS

Summary

This report documents the instrumentation, interfacing, and signal conditioning used to determine methods for remote cathodic control that are applicable to solar energy. Testing is being conducted at Marston WTP test site in Denver, Colorado.

The primary objectives of these tests are to assess the applicability of cathodic protection using photovoltaic cells and develop methods for its use. The assessments in this report give guidance for planning and conducting site investigations of cathodic signals by remote signal monitoring. Using photovoltaic cells for cathodic protection in remote areas and transmitting signals from these remote areas are twofold: (1) power lines are not installed, and (2) travel to a remote site for system performance and evaluation is unnecessary.

Conclusions

Monitoring cathodic signals remotely by satellite is feasible. Using photovoltaics is a practical and effective way to achieve cathodic protection and remote signal monitoring. Transmitting multiple signals from remote locations is applicable to other methods of monitoring. The use of other instrumentation concepts for remote monitoring should be studied.

PURPOSE

The purposes of this investigation were to determine the applicability of photovoltaics for remote cathodic control and to investigate the long-term effects of unprotected and protected cathodic

conditions on buried materials. Although this report covers testing at the Marston WTP site, the technology of remote cathodic control and signal monitoring is applicable to other types of cathodic work at different locales.

This report discusses the work at the Marston WTP site. New instrumentation for remote monitoring of cathodic measurement is described.

METHOD

Currently, several methods are used to monitor the behavior of cathodic signals on a buried structure. One method is making manual field measurements using hand-held instruments. The automated method described in this report uses electronic instrumentation, with which multiple signals are multiplexed and transmitted to remote areas for analysis by satellite.

THE MARSTON WATER TREATMENT PLANT TEST SITE

Pipe Layout

A map of the pipe layout is shown on figure 2 of this report. Each of the current-carrying wires is color labeled for identification. Of the 120 pieces of pipe, only half are cathodically protected. One-third of the unprotected pipes lie outside the cathodic field. These pipes are not influenced by the straight current fields as are those inside. The anode ground bed is about 30 meters from the pipe beds, assuring a well distributed cathodic current to each of the cathodically protected pipes. A water level sensor is installed (at location 6) next to the anode bed. A second water level sensor is installed at location 5, providing an indication of surface water level changes throughout the current passing field. There are soil moisture probes at locations 1, 2, and 3 of the buried pipe field, as shown on figure 2. The reference half cell is located near pipe 1, the pipe that is referenced to the cathodic regulator for control of the cathodic voltage output. Changes in the pipe-to-soil potential occurring in pipe 1 are reflected in the cathodic regulator output of the rest of the pipes. The terminal box and the Solapac cathodic voltage regulator are located next to each other to enhance the power distribution between solar panels, batteries, and regulator. The terminal box houses four storage batteries. A series of terminal strips and connectors interface the various electrical and electronic signals for the entire system.

Wiring Connections

A total of 120 pipes were buried at the Marston site for experimental studies using photovoltaic cathodic protection. Each of these pipes has a No. 8 and No. 12 wire connection. The No. 8 wire

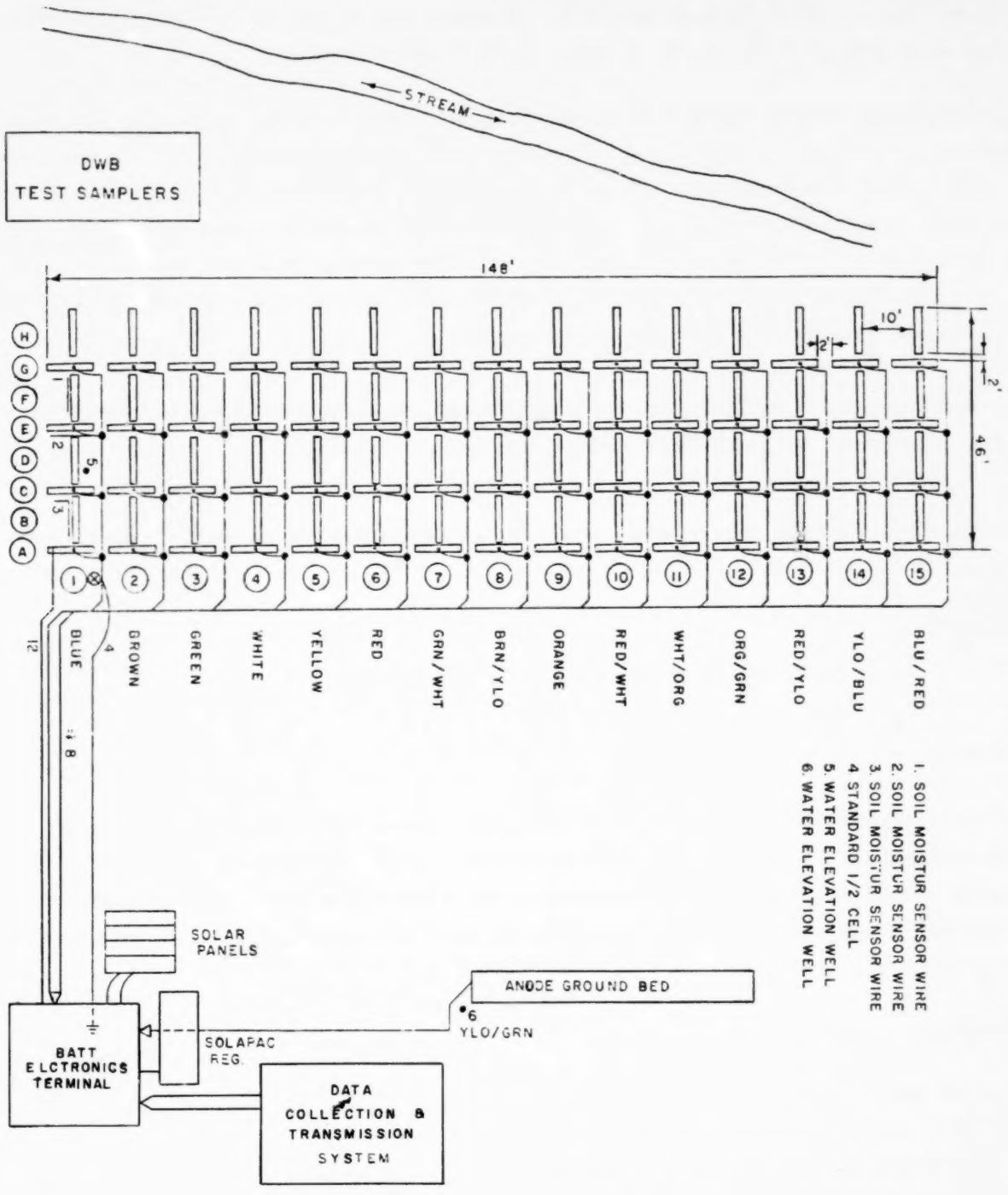


Figure 2. – Marston Water Treatment Plant site – pipe layout.

is used for cathodic current control. The No. 12 wire is used for making local pipe-to-soil measurements, although not every No. 12 wire goes to the cathodic regulator.

As shown on figure 2, a total of fifteen No. 8 insulated wires are extended from the pipe burial site to the cathodic controller. Some of the wire lengths are as long as 200 feet. All wires are buried 1-½ to 2 feet and spaced 1-½ feet apart. Two other No. 12 wires originate from the buried pipe site: the reference voltage wire from the standard half cell and the pipe potential wire. Both of these wires go to the cathodic regulator and controller. Because these two conductors do not carry heavy current, No. 12 wire was adequate. Care should be exercised in installation and burial of these wires so that the insulation is not damaged.

A series of other buried wires that carry signals from the electronic chassis to the 524 Data Collection System are part of the overall cathodic protection system.

In addition to the signal-carrying wire, there is a set of six soil moisture sensor wires. These wires are of special nature and are used for measuring soil moisture content. They are not being used at present.

SYSTEM AND INSTRUMENTATION

Photovoltaic Solar Panels and Batteries

The four SOLAREX 4330EG photovoltaic solar panels connect in a series-parallel combination, as shown on figures 3 and 4. The solar panel system is wired electrically as two strings of two series-connected panels. Four 6-volt storage batteries are housed in an adjacent covered box. The peak power from the four solar panels is 67 watts at full sunlight. Thus, the total system power is 134 watts at 24 volts.

The output specifications are as follows:

1. VOC (open circuit voltage) = 42 volts
2. ISC (short circuit current) = 4.45 amperes
3. Current at nominal voltage = 4.2 amperes
4. Effects of temperature:
   PP (peak power) = 0.3%/°C
   ISC = 3.93 mA/°C
   VOC = 176.4 mV/°C

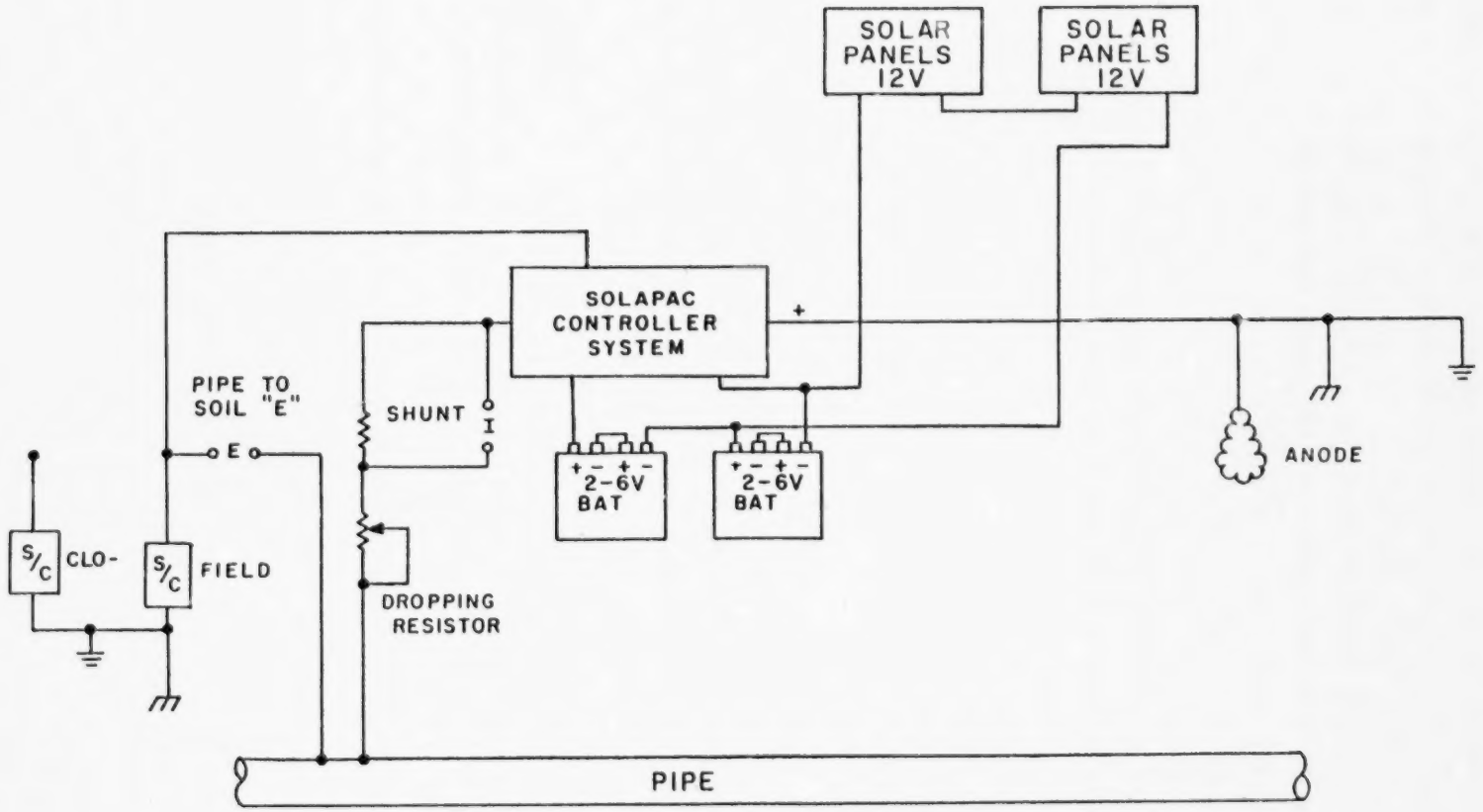


Figure 3. – Cathodic control block diagram.

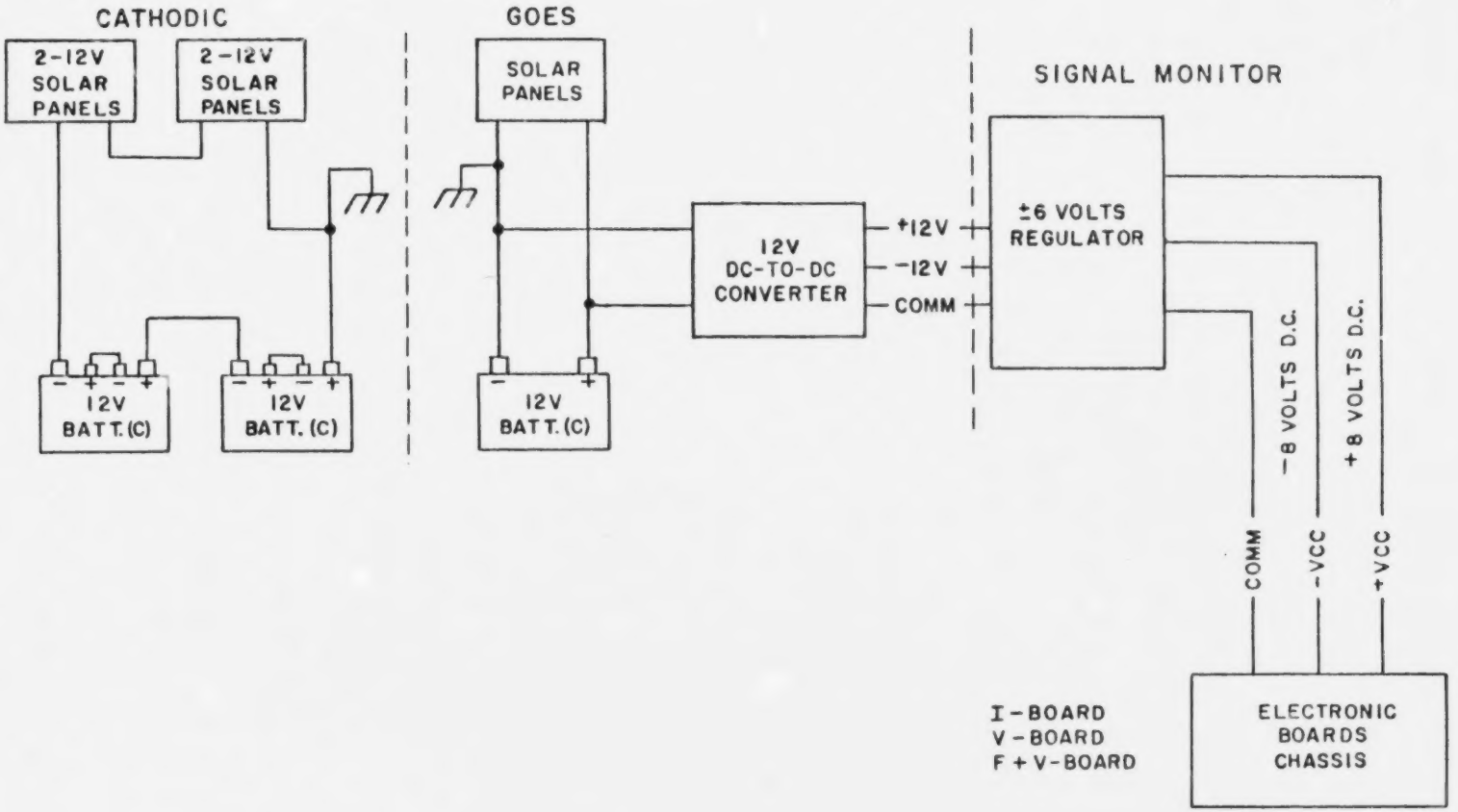


Figure 4. – Power hook-up block diagram.

The solar cells are encapsulated in silicone rubber, which is covered by tempered, textured glass, and held by an extruded anodized aluminum frame.

Basic principles of solar cells. – Solar cells are silicon semiconductor devices that convert light directly to electricity. When exposed to light, the photovoltaic cell produces a voltage at the terminals. When a load is connected across the terminals, current flows. This current is derived from the formation of "whole electron pairs" caused by the absorbed light photons.

The current output depends on the amount of light absorbed. During cloudy or hazy days, the current output is reduced. The current also is proportional to the surface area of the cells and the light intensity. To get a rough estimate of the average daily output of a system, multiply the current at nominal voltage by the number of peak sun hours per day. This yields the approximate average daily system energy output in ampere-hours. (For detailed information, see the *Installation and Maintenance Manual for Photovoltage Power System 4X330EG, Model No. 13400/24*, obtainable from Solarex.)

Solapac Regulator and Control

The cathodic voltage regulator consists of one Solapac type 211DHCT 28-volt, 450-watt regulator having zero to 4 volts output at 5 amperes. The load control circuit can operate from three parameters:

1. Load current,
2. Load voltage, and
3. Half-cell or reference potential.

Normally, the cathodic protection system operates with half-cell potential control.

The CP (cathodic protection) system provides an output to the load of 4 volts and 5 amps continuous operation with control capabilities to limit either the voltage or the current to a selected value. In addition, the system has provisions for possible time "ON", "OFF", operation at various selected periods and the possible use of an external copper-copper sulfate reference cell, which serves as a reference for the voltage differential to the structure to be protected at a preselected voltage.

The output control unit provides overcharging protection to the battery and a blocking diode to prevent battery discharge during darkness. A detailed procedure for interconnection, installation,

troubleshooting, and general information can be obtained from Solarex. A pictorial drawing of the Solapac regulator is shown on figure 5.

Solapac maintenance. – Detailed maintenance of the electronic equipment is not advisable except in a properly equipped workshop. The Solarex manual contains information on the adjustments that can be carried out under field conditions.

If a fault in the electronic control is suspected, the complete internal equipment may be removed from the box once the cable has been removed.

Note: Before disconnecting the batteries disconnect the interfacing circuit by turning the power switch to "OFF".

To remove the equipment, simply loosen the four screws – two at the top and two at the bottom of the rear mounting plate. When these screws are loose, the complete inside unit can be lifted out and replaced or repaired and reinstalled.

To inspect the circuit board behind the front panel remove the four screws. The front panel can then be folded down from the top as if it were hinged on the bottom edge. Stays, which hang on the back of the front panel facing downwards, prevent the panel from falling.

Checks can be made for any obvious fault, disconnection; etc., but as previously stated – it is not advisable to make any adjustments without the proper measuring equipment.

Mesonet Station (Probe)

The probe station mentioned in this report is the data collection platform of the GOES (Geostationary Operational Environmental Satellite) system. This probe station consists of the various sensors and the 524/525 data collection transmission system microprocessors. In the case of the Marston probe station, multiple levels of data processing are accomplished through synchronized multiplexing. A total of 64 channels are multiplexed three times daily and transmitted to the Bureau's Engineering and Research Center for analysis.

Data transmission and collection – The Handar 524/525 is a third generation microprocessor-based data collection system. The main application of the system is monitoring remote measurements where electrical line power or data collection facilities are not available.

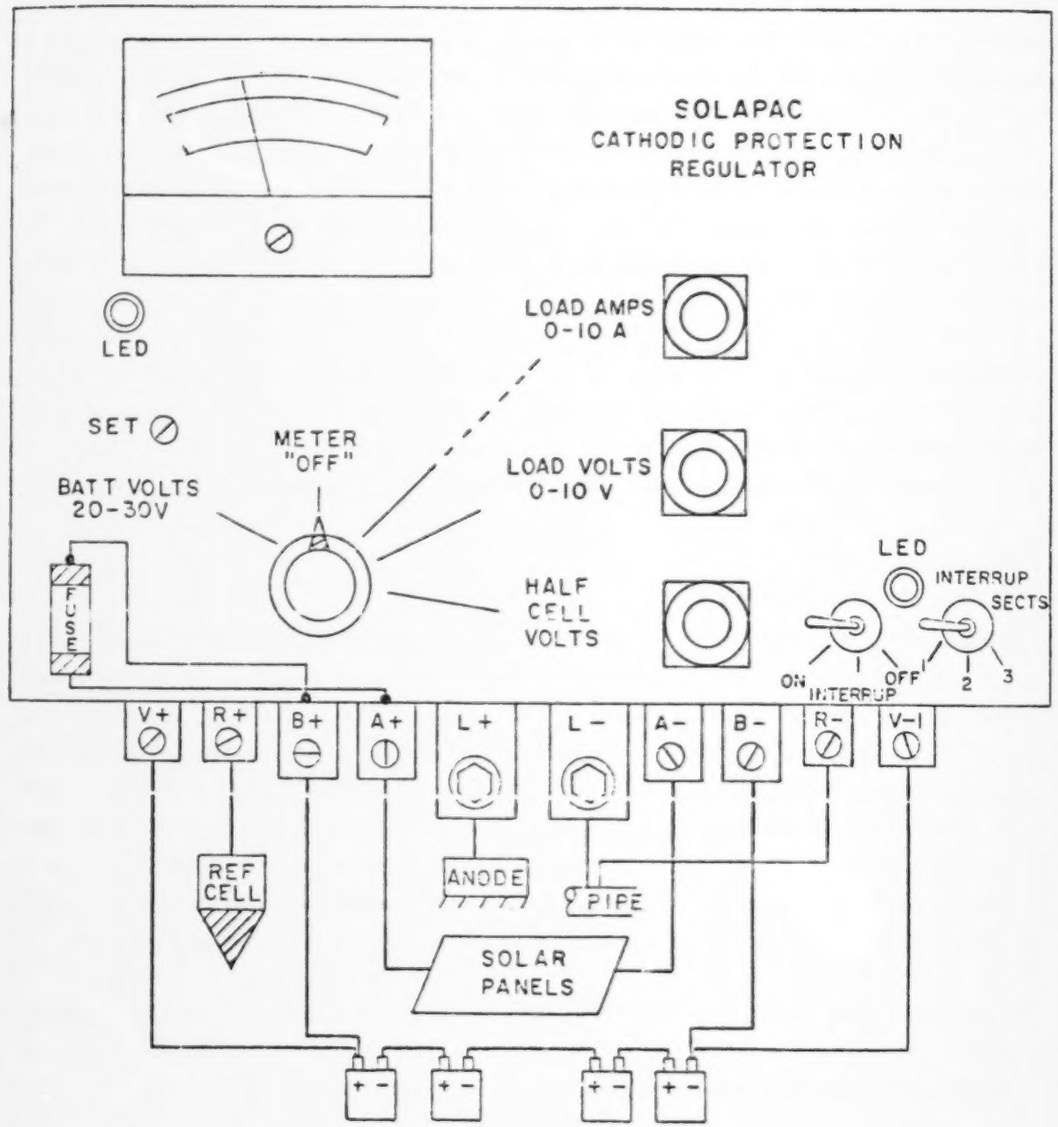


Figure 5. – Solapac cathodic protection regulator and circuit.

Measurements are made and data are collected at time intervals selected by the user. The data are transmitted to one of the geostationary satellites at intervals assigned by the satellite contracting agency. The satellite translates the data to a ground station. Data is disseminated to the user by the agency using the satellite. This data can be directed by modems, by dial-up phone service, through leased lines, or through mail; or it can be picked up at the office of the Division of Atmospheric Resources Research – as done here at the E&R Center. The Handar 524/525 system collects data over 12 input channels – four 16-bit-wide digital channels and eight analog channels. The user can program the system to any combination of analog and digital inputs. At the Marston WTP site, only the analog channels are being used. A block diagram of the data collection system is shown on figure 6.

Installation, maintenance, and operation of the GOES data collection system are maintained by personnel of the Division of Atmospheric Resources Research. (Instruction manuals and other material pertinent to the GOES system may be obtained from Handar Corporation, 1380 Borregas Avenue, Sunnyvale, CA 94086, TWX 910-339-9385. See the appendix for more information.)

Time Synchronization

The basic time synchronization is derived from the GOES data collection and transmission system at the Mesonet, or probe, station. The system consists of two basic components: the remote data multiplexer and the transmitter to the satellite. The remote data collection probe station is operated on a self-timed mode. Timing signals are generated internally at 10, 25, 40, and 55 minutes during each hour. A +12-volt signal from the probe station is applied to an automatic scan circuit on the display board to scan and multiplex the assigned sensors. As shown in table 1 (the timing table) each channel with its assigned sensor is interrogated four times per hour, 3 hours each day. The data are stored in memory. After the interrogation each channel is advanced. The data stored in memory are then transmitted to the satellite, at 5 minutes after the hour.

The assigned probe station channels are 2, 3, 4, 5, 6, 7, and 8. Each of these channels are multiplexed (advanced) once every hour. The scan cycle is repeated three times in a 24-hour day. Signal transmission to the satellite is frequency and synoptic time selective.

Multiple sensor channel assignment. – The synchronization of the various sensor probes to telemetry is accomplished by the +12-volt self-timing signal and the various multiplexer circuits used throughout the data automatic scan system. Each telemetry channel is assigned eight sensors. Each of the channels is multiplexed once an hour, thus scanning the assigned sensors three times a day. Channels 2 and 4 are assigned odd pipe numbered sensors; channels 3 and 5 are assigned

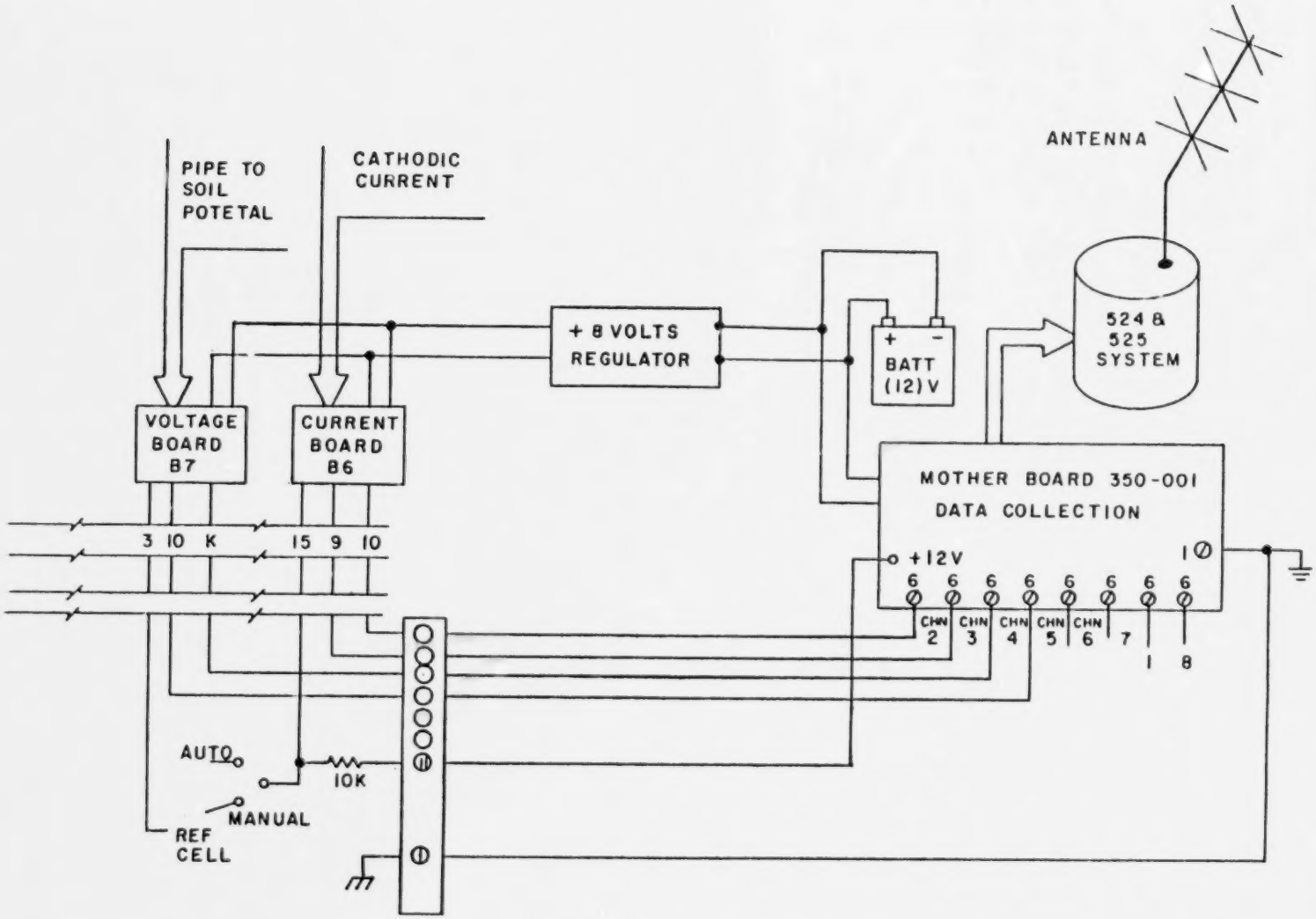
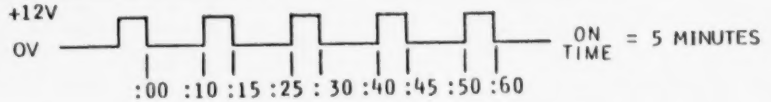


Figure 6. – Data collection system and cathodic signals interface block diagram.

Table 1. – Timing and channel selection.

		PIPE NO.	PIPE NO.	PIPE NO.	PIPE NO.	PIPE NO.	PIPE NO.	PIPE NO.	PIPE NO.
CURRENT CHANNEL NO.	CH. 2	15	13	11	9	7	5	3	1
	CH. 3	14	12	10	8	6	4	2	
VOLTAGE CHANNEL NO.	CH. 4	15	13	11	9	7	5	3	1
	CH. 5	14	12	10	8	6	4	2	
CHANNEL INDICATOR LED'S 1 = ON 0 = OFF	CBA	000	001	010	011	100	101	110	111
HOURS OF DATA COLLECTION	MOUNTAIN DAYLIGHT	1700	1800	1900	2000	2100	2200	2300	2400
		0100	0200	0300	0400	0500	0600	0700	0800
		0900	1000	1100	1200	1300	1400	1500	1600
HOUR WHERE SATELLITE TRANSMITS DATA FROM PREVIOUS HOUR OF DATA COLLECTION. TRANSMISSION SIGNALS OCCURS 5 MINUTES AFTER THE HOUR, EVERY HOUR	MOUNTAIN DAYLIGHT	1805	1905	2005	2105	2205	2305	2405	0105
		2605	0205	0305	0405	0605	0705	0805	0905
		1005	1105	1205	1305	1405	1505	1605	1705
	GREENWICH MEAN TIME	0:05Z	1:05Z	2:05Z	3:05Z	4:05Z	5:05Z	6:05Z	7:05Z
		8:05Z	9:05Z	10:05Z	11:05Z	12:05Z	13:05Z	14:05Z	15:05Z
		16:05Z	17:05Z	18:05Z	19:05Z	20:05Z	21:05Z	22:05Z	23:05Z
		ADD 1 HR. TO TIMES DURING STANDARD TIME PERIODS							

SATELLITE STATION TELEMETRY TRIGGER PULSE



MULTIPLEXER CYCLE INDICATOR SETTING

15 MIN	OFF	ON	OFF	ON	
30 MIN	OFF	OFF	ON	ON	

to even numbered pipe sensors. Presently, only channels 2, 3, 4, and 5 are used – giving capability of monitoring 32 sensors.

Scan circuit. – The scan circuit consists of one low-power operational amplifier (RCA 3078) and NPN transistor (2N2222) and a host of resistors and capacitors, as shown on figure 7.

The scan can be either manual or automatic. During manual operation, the circuit steps the multiplexer every 6 seconds. In an automatic mode, the scan signal is received from the 524 data collection system at the end of collection cycle. When all signal information has been collected the multiplexer can be stepped to the next position.

The setting of the system is monitored by five LED's on the display board (see fig. 7a). Three LED's are for the channel timing setting, labeled C, B, and A. The other two LED's indicate the multiplexer cycle and are labeled 15 M and 30 M. With the system in the manual mode, step the scan circuit until the LED's correspond with the present time period (table 1). For example, if it is 1:45 p.m. m.d.t., LED C will be on, B and A will be off, and both 15 M and 30 M will be on. Once the system is set, place the scan circuit in the "AUTO" mode.

Scan circuit theory of operation – automatic operation. – When a zero-volt signal from the 524 data collection is received at pin 18, the data collection has been completed, and a voltage change occurs at the negative input of the operational amplifier terminal. This change makes point A negative, producing a positive output at point B and a negative output at point C, the transistor output. Point A of the operational amplifier remains negative until the input at pin 18 becomes positive. During the transition to positive, capacitor C1 is charged, and that charge is held until the +12 volts reduce to zero. Then a negative signal is again produced at point C, telling the multiplexer to step to the next position.

Manual operation. – During manual operation the scan circuit goes into a low-frequency 10-cycle per minute, or 6-second, oscillation. This oscillation is maintained as long as the "AUTO-MAN-SCAN" selector switch is on a "MAN" position and switch No. 2 is on a "SCAN" position. Switch No. 2, "STEP SWITCH", is spring loaded in the "OFF" position. As soon as the lever of the "STEP SWITCH" is closed, oscillation stops. Thus, the operator can manually step through all multiplex positions.

Cathodic Protection Power System Current and Voltage Interface

Current measurements. – The current is measured on each of the pipes by putting a low resistor, or shunt, in series with the pipe power source (see fig. 8) and measuring the voltage drop across

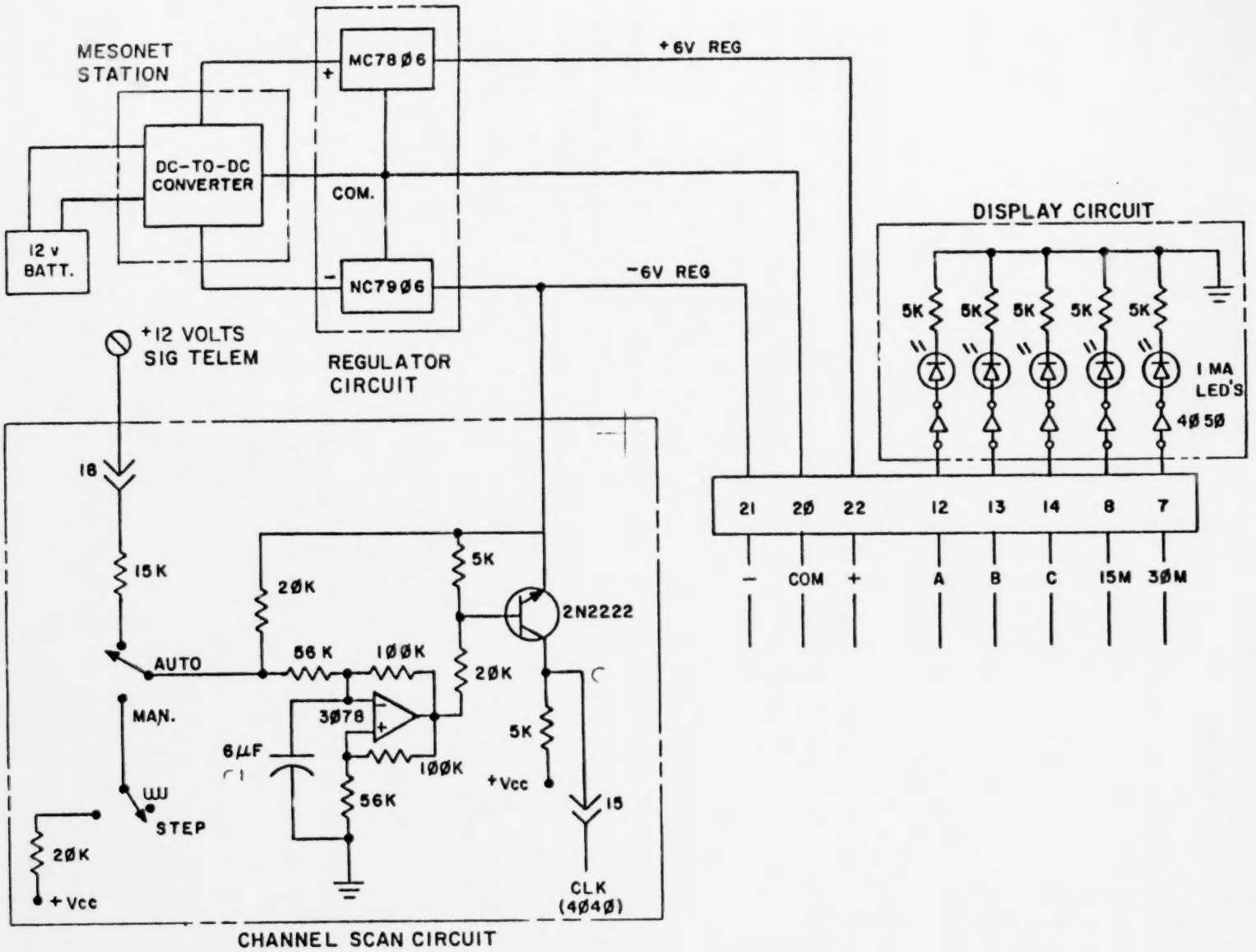


Figure 7. – Display and regulator board display circuit.

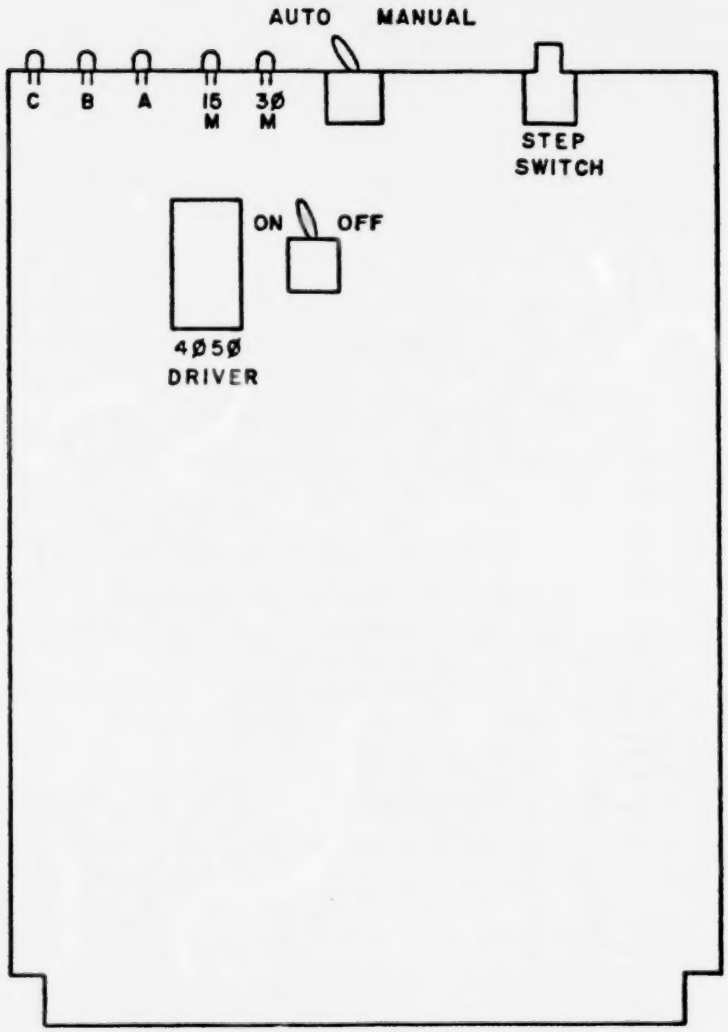


Figure 7a. – Display and regulator board.

the resistor. A total of 15 shunts measure the various cathodic currents of the pipes. The current measurements are made by applying a voltage drop across the shunt to an amplifier. The amplifier gain is adjusted until the output is properly interfaced to the 524 data collection system. A detailed description of the current measurement is given in "Current Multiplexer and Amplifier Board."

Series Resistor

The pipe-to-soil potential of each of the pipes is adjusted by a variable resistor connected in series with the pipe power source as shown on figure 9 and in table 2. As the polarization or the soil resistance change, the pipe-to-soil potential changes. The variable series resistor is adjusted to

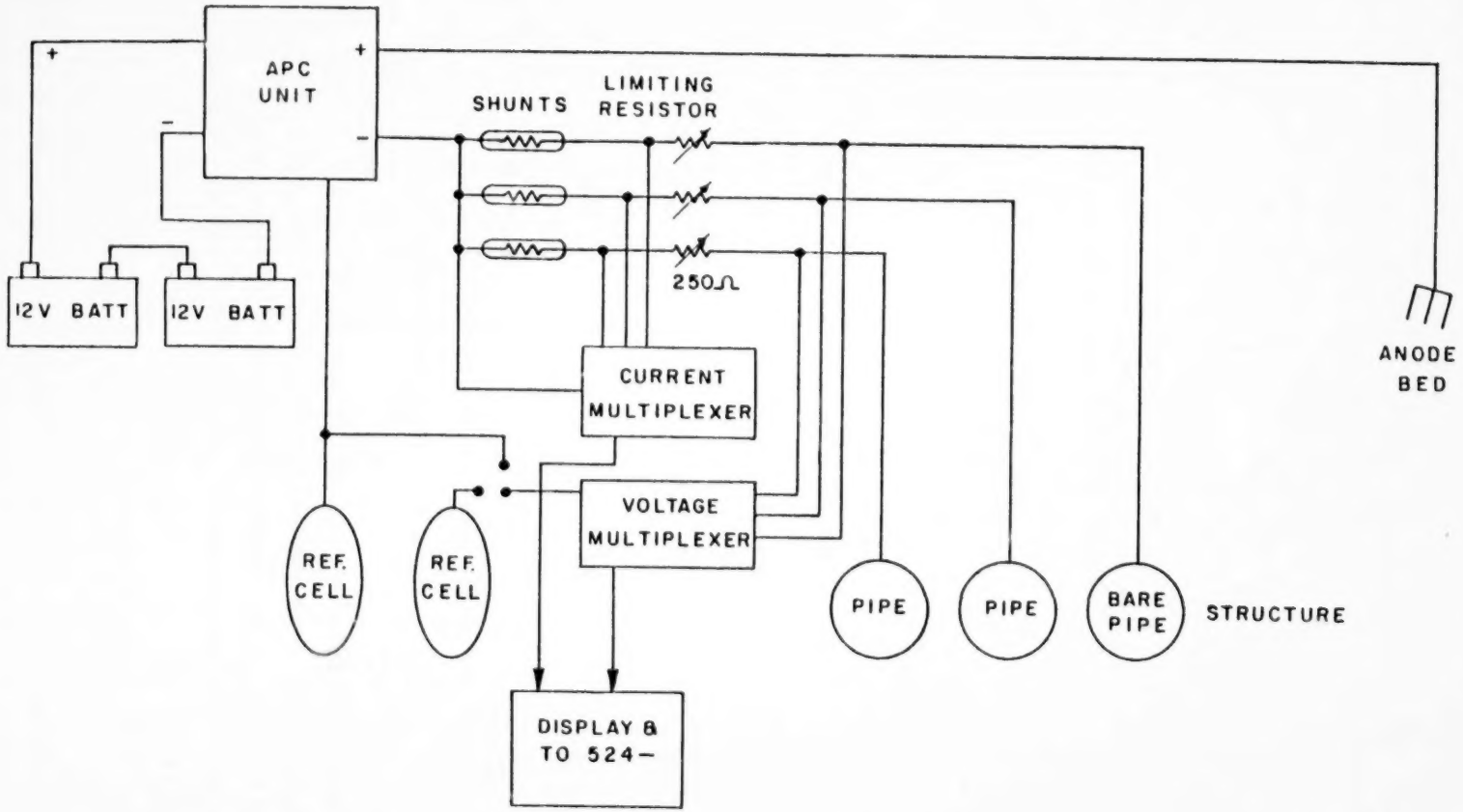


Figure 8. – Cathodic protection wiring diagram.

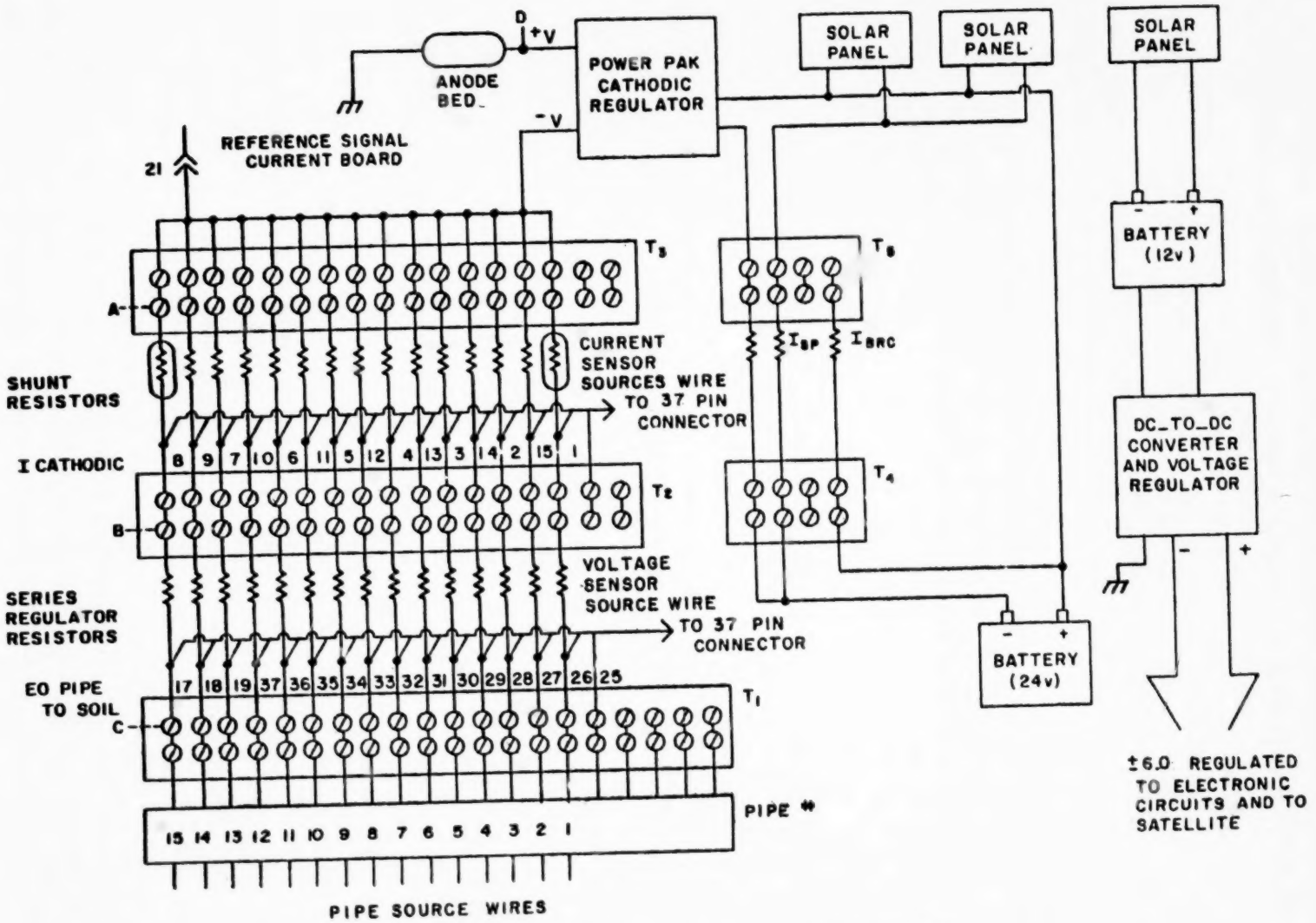


Figure 9. – Cathodic protection power system current and voltage interfacing.

Table 2. – Pin connection.

Current Board

Pipe No. Fig. 10	Current sensor source wire color code fig. 10	37 Pin Connector fig. 10	4051 Ch. No.	4051 Pin No.	Output ch. No.	Channel indicator		
						C	B	A
15	wht, brn, grn	8	0	13	2	0	0	0
14	wht, blk, gry	9	0	13	3	0	0	0
13	wht, blu, blk	7	1	14	2	0	0	1
12	wht, red	10	1	14	3	0	0	1
11	wht, org, gry	6	2	15	2	0	1	0
10	wht, brn, org	11	2	15	3	0	1	0
9	wht, blk, grn	5	3	12	2	0	1	1
8	wht, pur, org	12	3	12	3	0	1	1
7	wht, brn	4	4	1	2	1	0	0
6	wht, org, blu	13	4	1	3	1	0	0
5	wht, yel	3	5	5	2	1	0	1
4	wht, grn, org	14	5	5	3	1	0	1
3	wht, pur, brn	2	6	2	2	1	1	0
2	brown	15	6	2	3	1	1	0
1	wht, gry, brn	1	7	4	2	1	1	1
0	_____	_____	7	4	3	1	1	1

Voltage Board

Pipe No. fig. 10	Voltage sensor source wire color code fig. 10	37 Pin connector fig. 10	4051 Ch. No.	4051 Pin No.	Output ch. No.	Channel Indicator		
						C	B	A
15	wht, yel, red	17	0	13	4	0	0	0
14	wht, org, red	18	0	13	5	0	0	0
13	wht, brn, blu	19	1	14	4	0	0	1
12	wht, org, pur	37	1	14	5	0	0	1
11	wht, grn	36	2	15	4	0	1	0
10	blue	35	2	15	5	0	1	0
9	orange	34	3	12	4	0	1	1
8	wht, grn, yel	33	3	12	5	0	1	1
7	yellow	32	4	1	4	1	0	0
6	wht, blk, pur	31	4	1	5	1	0	0
5	wht, yel, brn	30	5	5	4	1	0	1
4	wht, brn, red	29	5	5	5	1	0	1
3	wht, yel, blu	28	6	2	4	1	1	0
2	wht, org	27	6	2	5	1	1	0
1	wht, blk, yel	26	7	4	4	1	1	1
0	_____	_____	7	4	5	1	1	1

compensate for these changes, keeping the pipe-to-soil potential at the desired voltage level. A total of 15 resistors are used to control the pipe-to-soil potential at the Marston WTP site.

Voltage (Multiplex) Board – Basic Principles

The voltage board consists of two 8-position multiplexers (RCA 4051) and four operational amplifiers on a single quad chip (LF 444).

The voltage board measures the pipe-to-soil potential with reference to the potential of the standard half cell. The differences in potential between the pipe and the standard cell are then applied to the 524 data collection system of the Mesonet station for satellite transmission.

Voltage Board – Theory of Operation

The operation of the pipe-to-soil multimeasurement circuit is based on multiplexing the input signal at the proper time. In general, the voltage board consists of signal multiplexers, an operational or instrumentational amplifier, and some form of signal timing logic. On figure 10, the pipe potential is multiplexed and the standard is used as a reference. The reference signal of the standard half cell is applied directly to the noninverting input of the second stage of the operational amplifier. The pipe potential is applied to the various inputs of the RCA 4051 multiplex chip. The output signal from the 4051 chip is applied to the noninverting input of the first stage of a differential amplifier, and the inverting input is referenced to ground. An offset control is provided to balance the signal to the desired reference level.

Current Multiplexer and Amplifier Board

The current multiplexer and amplifier board for an eight-channel system consist of four operational amplifiers, on one chip, and one RCA 4051 multiplexer. A gain control provides the desired amplification factor, and an offset control provides the balance of the signal to required levels (see fig. 11). Signals from the current shunt are applied to an operational amplifier and to the multiplexer. The current monitoring system was designed to interface with GOES satellite system for cathodic measurements and evaluation of metallic pipes. The current monitoring system described in this report consists of two CA 4051 multiplexers, two low-power CA 324 quad amplifiers, and one CA 4040 dual up counter. Each of the 4051 multiplexers are stepped in unison by the dual up counter. The output signal from the multiplexer is conditioned and amplified by the amplifier. This amplified signal then is applied to the input of the mother board 524 microprocessor for storage and transmission to the GOES satellite.

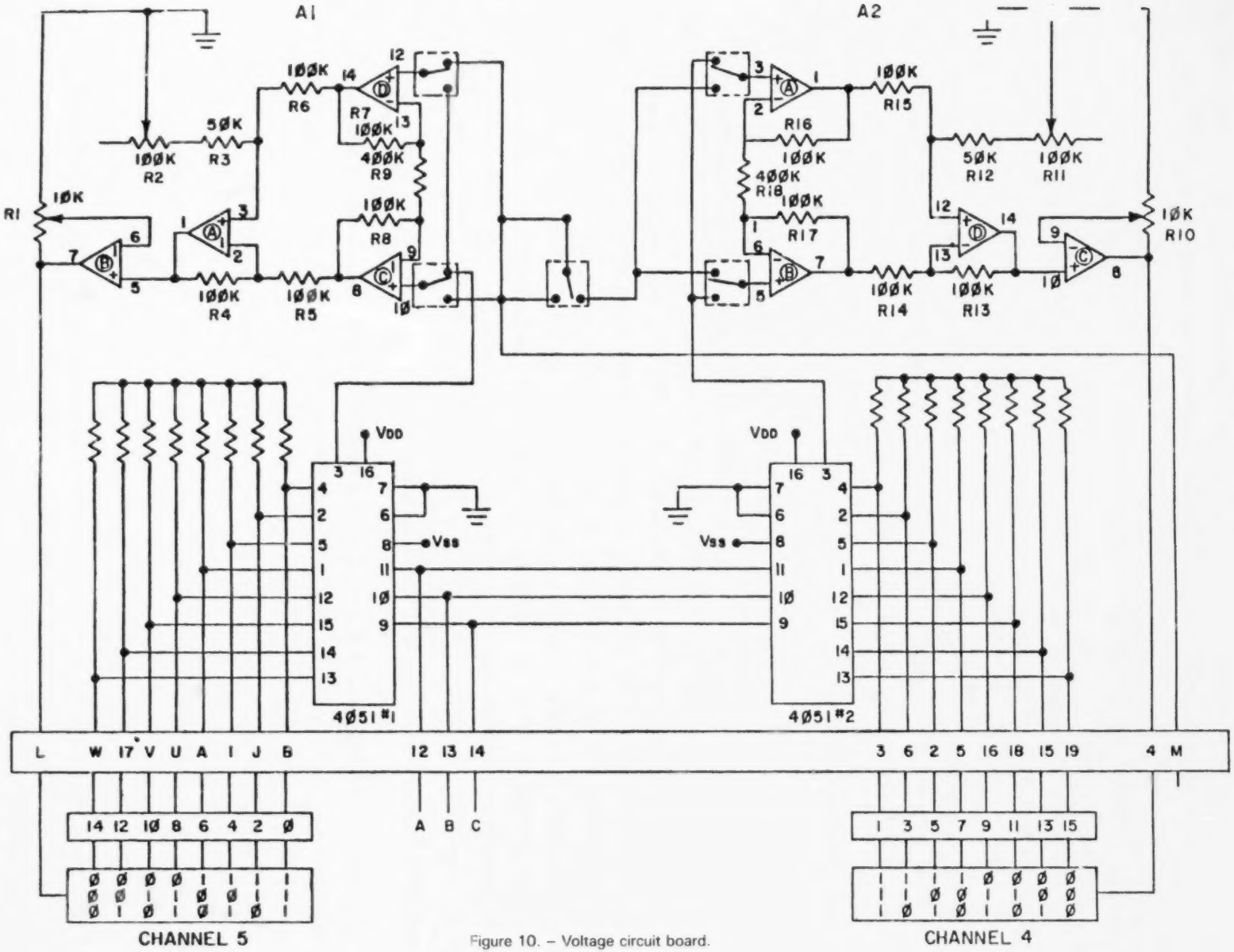


Figure 10. – Voltage circuit board.

Theory of operation. – The voltage drop across the calibrated current shunt indicates the current used to cathodically protect the pipe. One end of each current shunt is connected to the negative side of the cathodic voltage power supply. The other end goes to the collector of the cathodic voltage regulator. Figure 11 shows a circuit diagram of the dual 8-channel current monitoring system. The collector end of each current shunt is connected to a corresponding channel in the CA 4051 multiplexer.

Although the current monitoring system contains 16 channels, each of the subsystems contains 8 channels. Because there are two subsystems per board, each of the subsystems are identical.

Timing. – The output of Q3 (fig. 7) is applied to the input of a RCA 4520 dual binary up counter or a RCA 4040 binary ripple 12-stage counter. The current and amplifier board also holds the BCD timer, which drives the multiplexer time sequence.

Voltage Regulator and Power Supply

Power to the electronic circuits is provided by a dual supply 12-volt d.c.-to-d.c. converter located at the Mesonet station. One +6-volt regulator (MC7806) and one −6-volt regulator (MC 7906) reduce the 12-volt power source to a steady plus or minus 6 volt for circuit operation (see fig. 7).

Data Collection, Transmission, and Retrieval

Signals from the cathodic protection system are stored in the 524/525 data collection transmission system. These signals are sampled four times each hour by the data collector. A total of 64 signals can be multiplexed during an 8-hour period (see fig. 12). At the end of each hour, the stored signals are transmitted to the satellite by the 524/525 data collection transmission system. These signals are then retransmitted to the designated receiving station at the Bureau's E&R Center. The satellite signals are received at the E&R Center by a parabolic dish antenna and sent to a central data distribution facility where the data are demodulated and presented in engineering units.

A format of our data presentation for the Marston WTP site is shown in table 3. Sixty-four data samples are provided three times daily. These data samples are given in the engineering units for current (C), voltage (V), and precipitation (P). The last row, pipe zero, has a fixed signal for channel identification with reference to real time. The current on row zero has a value of 0.5 and the voltage on row zero has a value of zero. If these values appear somewhere other than row zero, the multiplex scan is not in synchronization with real-time transmission (see table 3).

Data printout for the Marston WTP site can be called from a remote area by telephone modem or from the Division of Atmospheric Resources Research (System Development Branch) office.

Calibration

Three items are required for calibration:

- One hand-held digital voltmeter
- One 37-pin "D" style connector with all voltage inputs connected together and all current inputs connected together
- One small regular screwdriver.

To calibrate the system, place the scan circuit in the manual mode (fig. 7a) and reset the system (fig. 11a). Zero all four input channels.

Plug the 37-pin connector into the system input and tie the current inputs to the reference signal. Measure the output starting with the current board, channel 2. Adjust offset R11 until it is at zero. The same procedure is used for channel 3 using R2 (fig. 11a).

For the voltage board, channels 4 and 5, connect the inputs to the reference cell and follow the same procedure used for the current board (fig. 10a).

After all the channels have been zeroed, adjust the output signals to the input signals. Shut off the power to the system before connecting the sensor source input connector. When power is restored, perform a system reset.

Using a voltmeter, locate the largest signal by measuring the voltage across the shunt resistors, points A and B of figure 9, that correspond with the odd-numbered pipes. Once the largest signal is identified, step the scan circuit (fig. 7) until the display corresponds with the correct pipe number. Adjust the gain R10 (fig. 11a) until the output signal is 10 times the input signal. Calibrate channel 3 to the even numbered pipes using R1 (fig. 11a).

For the voltage board, channel 4, measure the voltage from point C (fig. 9) and the reference cell on all the uneven pipe numbers. Once the largest signal is found, adjust the gain R10 (fig. 10a) until the output is 2.5 times the input. Calibrate channel 5 to the even numbered pipes using R1 (fig. 10a).

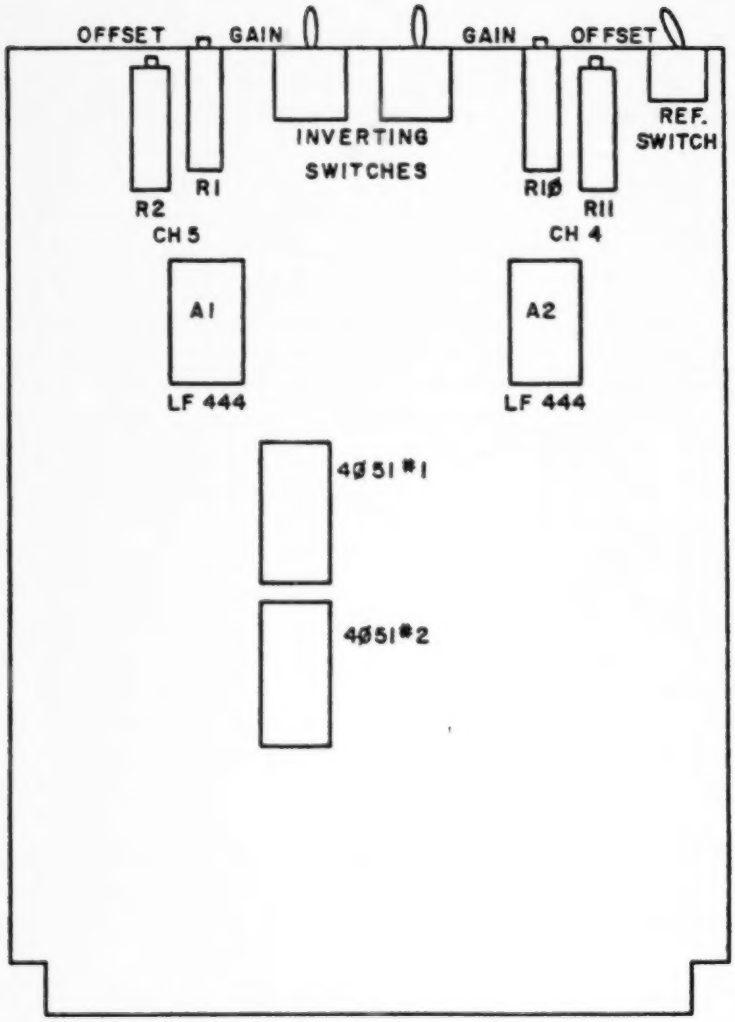


Figure 10a. – Voltage circuit board component layout.

Maintenance

Electronic circuit boards. – The electronic circuits were designed for trouble-free use and unattended operation. The current, voltage, and display boards are modular. When a malfunction has been localized to a particular board, all that is necessary to remedy the problem is to replace the defective board.

Detailed maintenance of the electronic equipment in the field is only recommended in a properly equipped workshop.

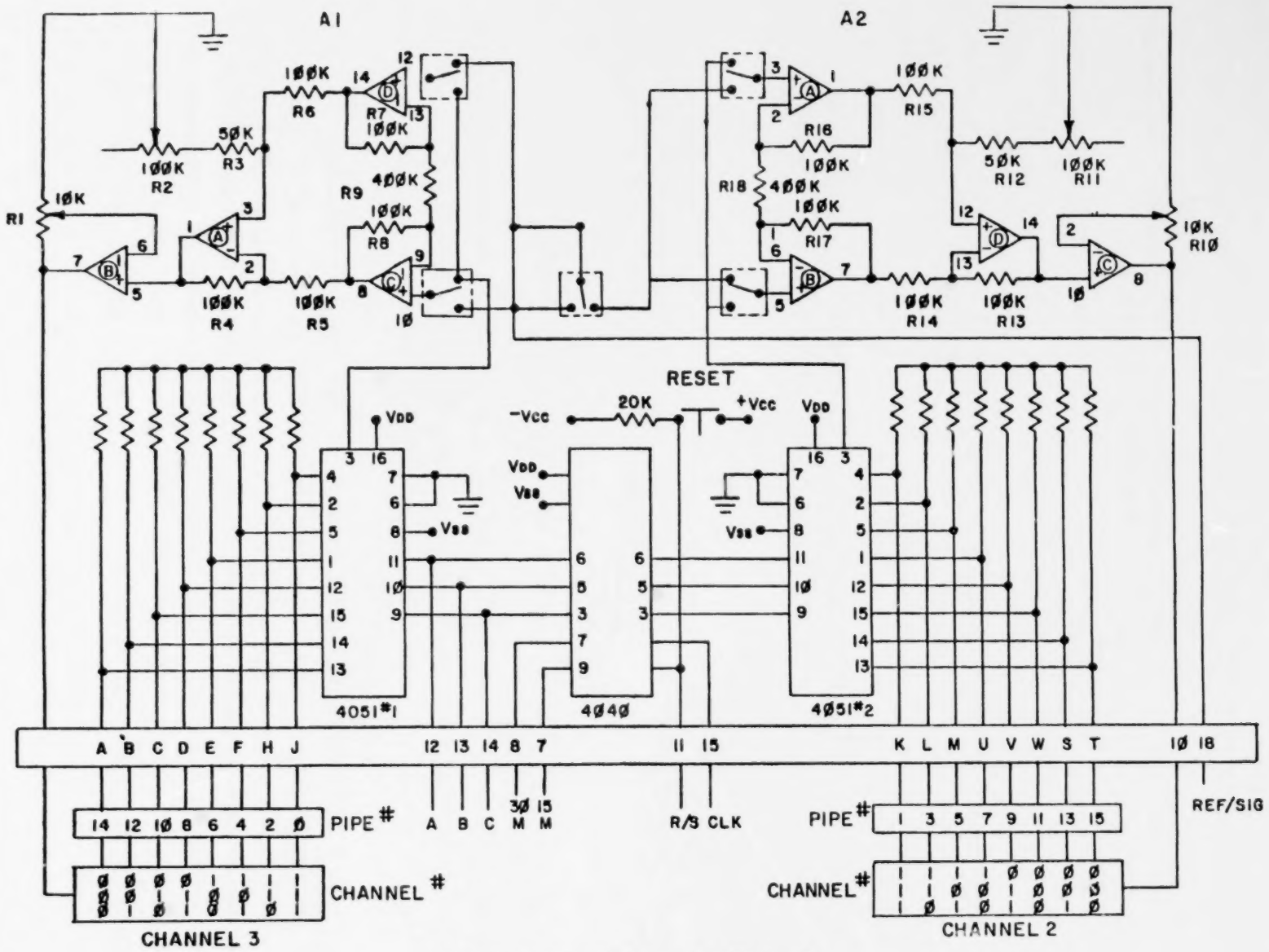


Figure 11. – Current multiplexer and amplifier board.

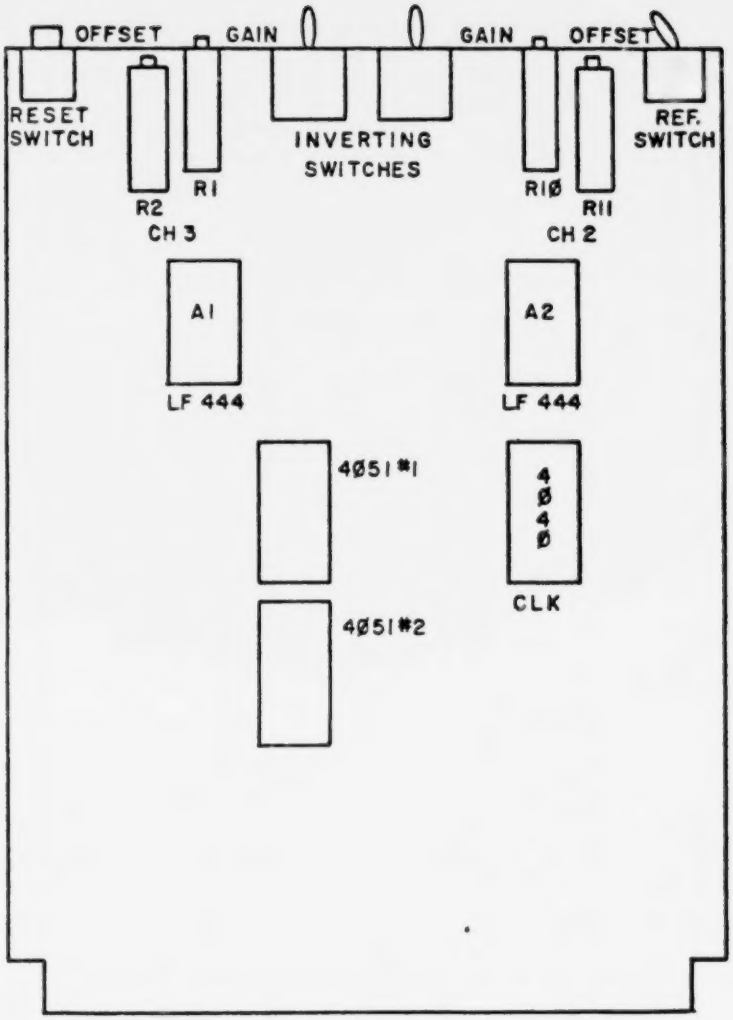


Figure 11a. – Current multiplexer and amplifier board component layout

Battery Maintenance. – Periodic inspection of the battery electrolyte level may be needed, depending on the charge and temperature conditions. The battery terminal posts and cables should also be checked during this inspection.

Solar panel maintenance. – Although the solar panels are relatively maintenance free, they should be cleaned and inspected regularly. The encapsulation of the panels should be checked to ensure they are weatherproof and the silicon rubber seals are in good condition. In most areas rain and snow will keep the panel surfaces clean; but in areas where there is a lot of dust, cleaning the panel may be necessary to prevent output degradation.

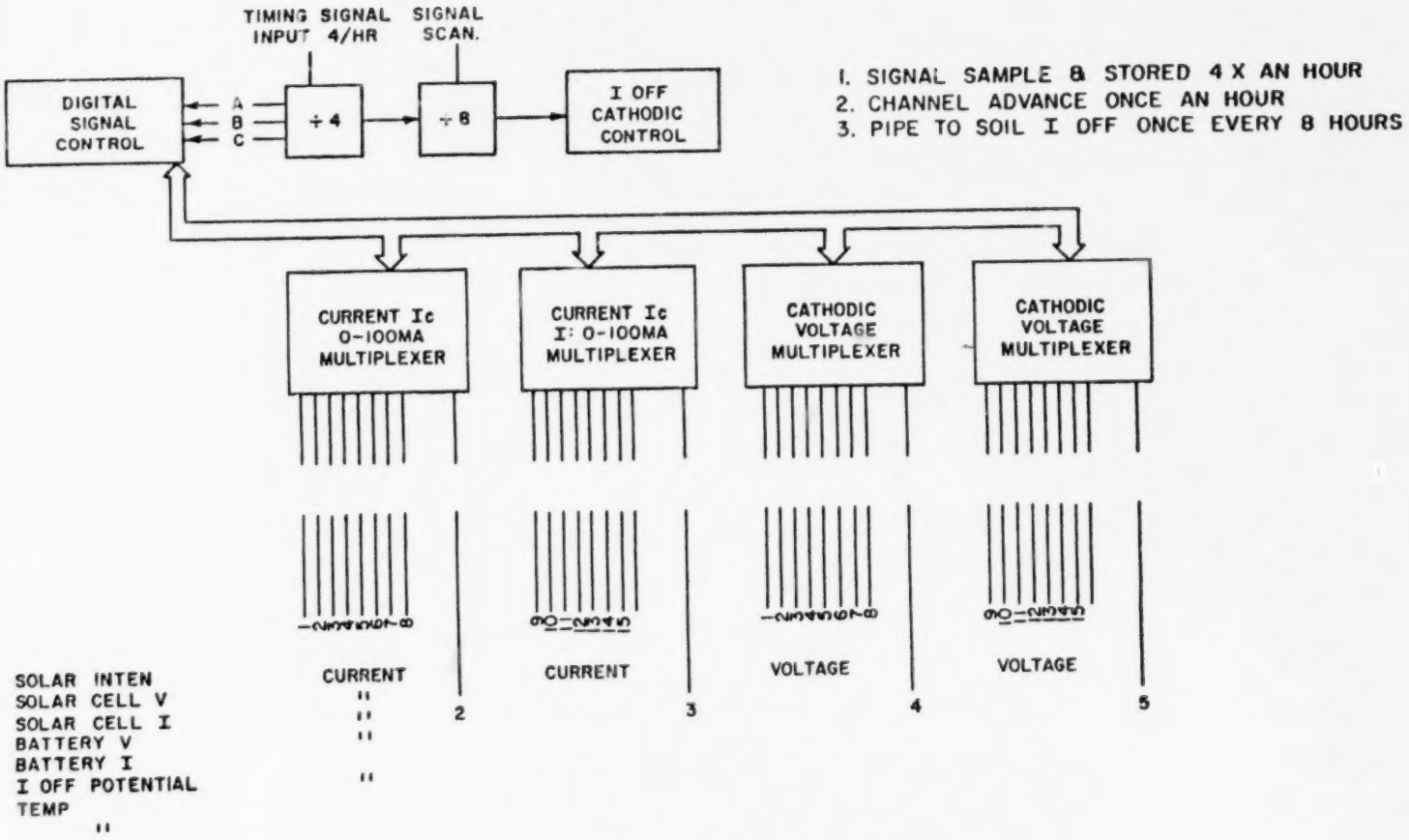


Figure 12. – Energy solar cathodic protection circuits.

Table 3. – Data presentation format for the Marston WTP site

PIPE No.	TIME	C	V	H	P	TIME	C	V	H	P	TIME	C	V	H	P
15	00					08					16				
14	00					08					16				
13	01					09					17				
12	01					09					17				
11	02					10					18				
10	02					10					18				
9	03					11					19				
8	03					11					19				
7	04					12					20				
6	04					12					20				
5	05					13					21				
4	05					13					21				
3	06					14					22				
2	06					14					22				
1	07					15					23				
0	07					15					23				

C = current (mA)
V = PIPI to soil potential
H = house keeping signals
P = precipitation

Pipe Current (mA)/Voltage (Volts) record
Station: MRL
Date

*Input to all channels is 0 to 5 volts
Channel output is A/D 0 to 255 counts

Maintenance of other equipment. – Refer to the bibliography for the maintenance of the Solapac [1] and probe station [2].

TEST RESULTS

Photovoltaic remote cathodic control, interfacing, multiplexing, and signal monitoring by satellite has proved effective. Every day 34 channels of information on the cathodic condition of 90 buried, 10-foot-long pipes are transmitted for analysis to the E&R Center by satellite. Data can be reported hourly, daily, weekly, biweekly, monthly, or stored to be reported when needed. In general, data are reported on the pipe-to-soil potential, cathodic currents, electronic drift from ground potential, and time synchronization of the data multiplexer.

The electronic signal condition and multiplexing system was designed specifically for cathodic signal monitoring. The features of the system are:

- Low power,

- Floating power source,
- Self monitoring of ground drift,
- Time synchronization,
- Easy maintenance with modular plug-in containing channel identification, and
- Flexibility of interfacing between cathodic controlled regulator and the 524/525 data collection transmission system.

BIBLIOGRAPHY

[1] Solarex Corp., *Installation and Maintenance Manual for Photovoltaic Power System 4X4330EG, model No. 13400/2A.*

[2] Electronic Techniques, Inc., *Instruction Manual for Meteorological Surface Observation Networks.*

[3] Solarex Technical Staff, *Making and Using Electricity from the Sun.*

[4] Parker, Marshall E., *Pipeline Corrosion and Cathodic Protection.*

[5] *RCA COS/MOS Integrated Circuits,* RCA Solid State Data Book.

[6] *RCA Linear Integrated Circuit,* RCA Solid State Data Book.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.